Dynamics of the Chiral Phase Transition*

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Since the quark masses are fairly small, the basic QCD Lagrangian is approximately invariant with respect to chiral transformations. However, due to the self-interaction of the fields, this symmetry is spontaneously broken and the in the order parameter is finite in the vaccum. This basic feature of the strong interaction may be probed in high-energy nuclear collisions.

The linear σ model has been widely used to explore this phenomenon and it is therefore of interest to explore its phase structure. Though not realized in nature, the case of vanishing quark masses (leading to perfect O(4) symmetry) is of special theoretical interest as it makes instructive contact with other, more fundamental approaches, such as lattice gauge treatments.

The equilibrium values of the order parameter ϕ_0 can be obtained by requiring the free energy to have an extremum, $(\partial F_T/\partial\phi_0)_T = 0$, or, equivalently, demanding that $\mu_0^2\phi_0$ vanish, where μ_0 is the effective mass for ϕ_0. The resulting phase structure is illustrated in Fig. 1.

The ground-state minimum in F occurs at $\phi_0 = v$ and it moves steadily inwards as the temperature is increased. For temperatures below $T_0 \approx 130$ MeV there is a single (fairly large) equilibrium value of ϕ_0, Above T_0 a two-phase structure develops with a meta-stable minimum occurring at $\phi_0 = 0$ and a maximum which joins the outer minimum at $T_c \approx 190$ MeV. Above T_c there is only the symmetric minimum and thus the system prefers to have chiral symmetry.

The corresponding evolution of the effective quasiparticle masses $\mu_{\|}$ and $\mu_\perp$ is shown in Fig. 2. In equilibrium we always have $\mu_0^2 \leq \mu_\perp^2 \leq \mu_{\|}^2$ (the equality signs hold only for $\phi_0 = 0$).

Because of this general structure of the free energy for vanishing quark masses, the system displays a first-order phase transition at T=T_c, where the order parameter abruptly changes from a fairly large finite value to zero.

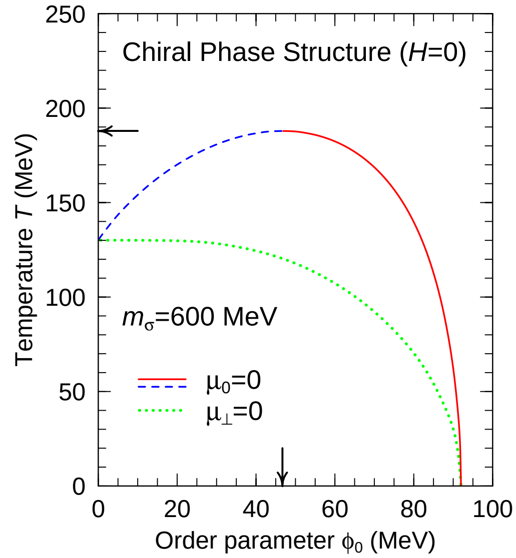

Figure 1: The loci of stable (solid) and unstable (dashed) equilibria and the critical boundary (dots) as well as the effective field is supercritical ($\mu_\perp^2 < 0$).

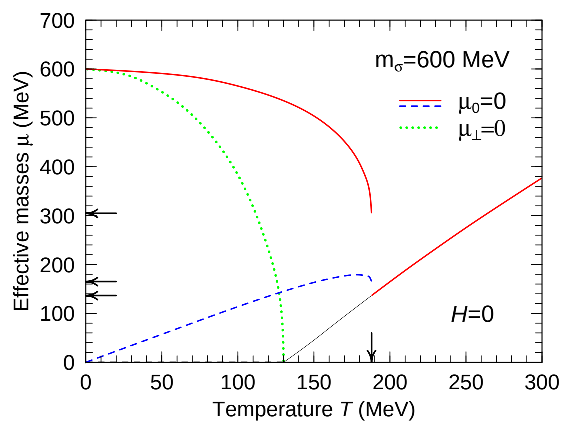

Figure 2: Equilibrium values of the effective masses for longitudinal (solid) and transverse (dashed) quasiparticle modes, as well as the longitudinal mass (dots) along the critical boundary (where $\mu_\perp^2 = 0$); the (degenerate) mass values in the symmetric metastable equilibrium are shown by the thin solid curve.

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